Partitioning the LIS/OTD lightning climatological dataset into separate ground and cloud flash distributions

W. J. Koshak, Earth Science Office, Mail Stop VP61, NASA Marshall Space Flight Center (MSFC), Huntsville, AL 35805.
R. J. Solakiewicz, Chicago State University, Department of Mathematics & Computer Sciences, 9501 South King. Drive, Chicago, IL 60628.

1. INTRODUCTION

Presently, it is not well understood how to best model nitrogen oxides (NO_x) emissions from lightning because lightning is highly variable. Peak current, channel length, channel altitude, stroke multiplicity, and the number of flashes that occur in a particular region (i.e., flash density) all influence the amount of lightning NO_x produced. Moreover, these 5 variables are not the same for ground and cloud flashes; e.g., cloud flashes normally have lower peak currents, higher altitudes, and higher flash densities than ground flashes [see (Koshak, 2009) for additional details]. Because the existing satellite observations of lightning (**Fig. 1**) from the Lightning Imaging Sensor/Optical Transient Detector (LIS/OTD) do not distinguish between ground and cloud flashes, which produce different amounts of NO_x, it is very difficult to accurately account for the regional/global production of lightning NO_x. Hence, the ability to partition the LIS/OTD lightning climatology into separate ground and cloud flash distributions would substantially benefit the atmospheric chemistry modeling community. NO_x indirectly influences climate because it controls the concentration of ozone and hydroxyl radicals in the atmosphere. The importance of lightning-produced NO_x is emphasized throughout the scientific literature (see for example, Huntrieser et al. 1998). In fact, lightning is the most important NO_x source in the upper troposphere with a global production rate estimated to vary between 2 and 20 Tg(N)yr^{-1} (Lee et al., 1997), with more recent estimates of about 6 Tg(N)yr^{-1} (Martin et al., 2007). In order to make accurate predictions, global chemistry/climate models (as well as regional air quality models) must more accurately account for the effects of lightning NO_x. In particular, the NASA Goddard Institute for Space Studies (GISS) Model E (Schmidt et al., 2005) and the GEOS-CHEM global chemical transport model (Bey et al., 2001) would each benefit from a partitioning of the LIS/OTD lightning climatology.

In this study, we introduce a new technique for retrieving the ground flash fraction in a set of *N* lightning observed from space and that occur within a specific latitude/longitude bin. The method is briefly described and applied to CONUS lightning that have already been partitioned into ground and cloud flashes using independent ground-based observations, in order to assess the accuracy of the retrieval method. The retrieval errors are encouragingly small.

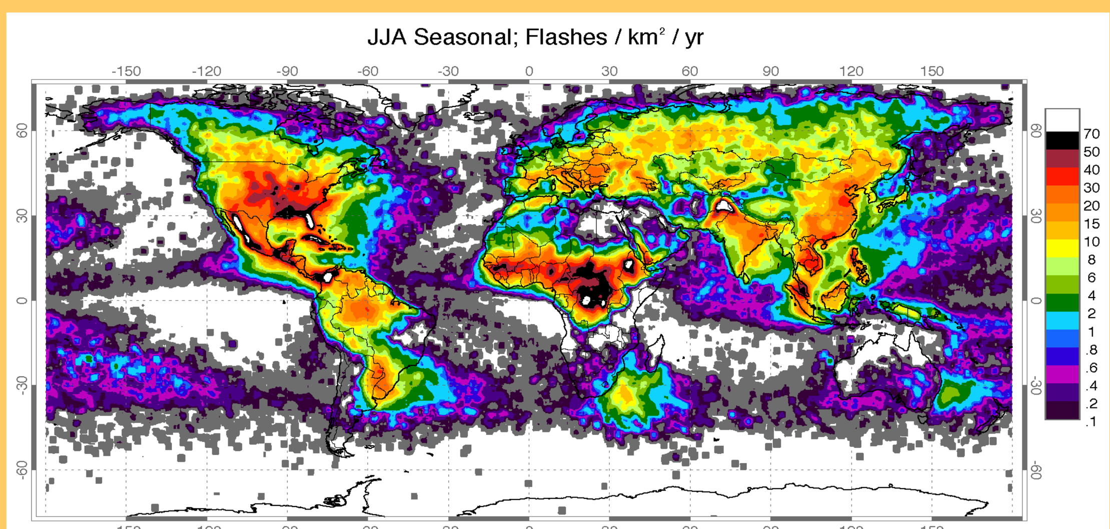


Figure 1. Sample LIS/OTD lightning climatology.

2. LIGHTNING OPTICAL PROPERTIES

In the study by Koshak (2007) the frequency distributions of several optical properties of lightning (i.e. flash radiance, flash area, flash duration, # of optical groups in a flash, # optical events in a flash) as observed from space were determined for both ground and cloud flashes; it was found that the distributions overlapped considerably thereby making it difficult to use the space-based optical measurements to discriminate between ground and cloud flashes. However, it was also shown that the means of these distributions are quite different for ground and cloud flashes. *A need to analyze the means has motivated the flash discrimination process discussed in section 3.* **Fig. 2** shows a sample of the flash area distribution for both ground and cloud flashes. We have extended the Koshak (2007) investigation by obtaining the distributions of the *maximum # events in a group* (MNEG) and the *maximum group area* (MGA). The distributions of MNEG for ground and cloud flashes are shown in **Fig. 3**.

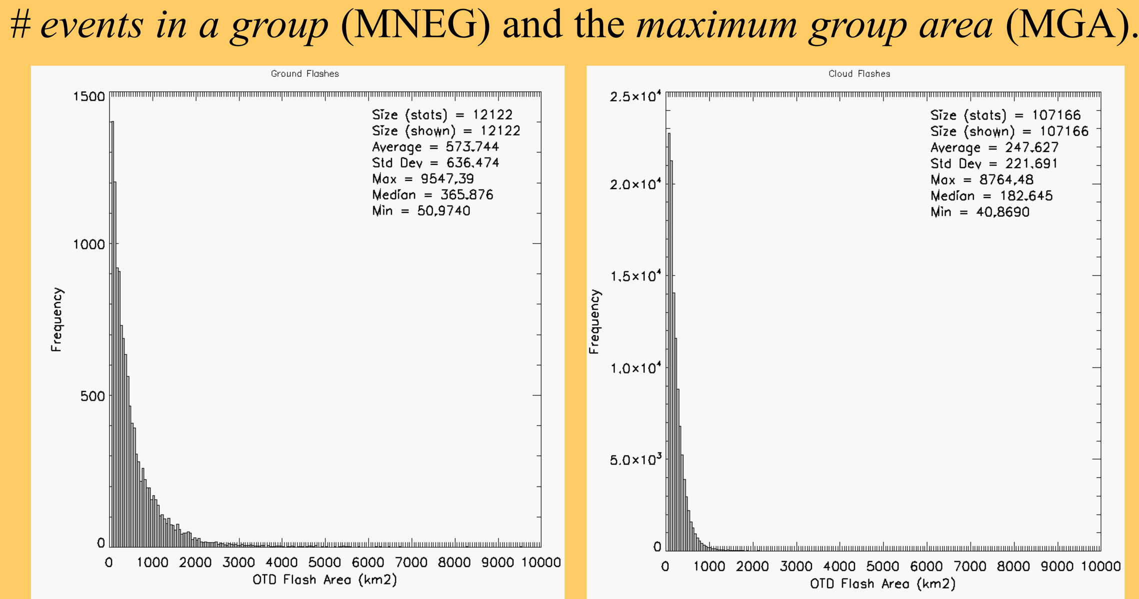


Figure 2. Distributions of flash area.

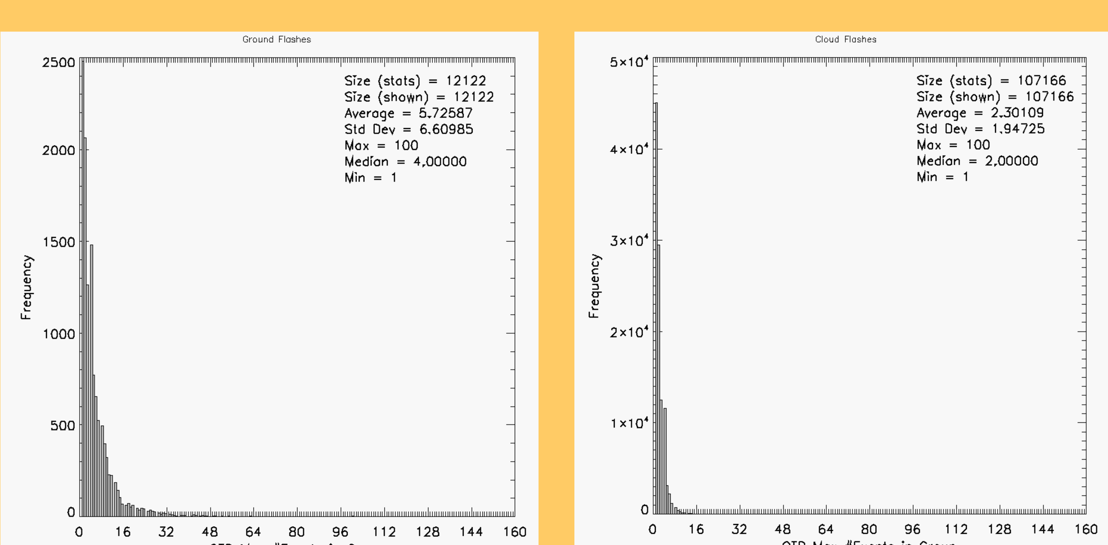


Figure 3. Distributions of MNEG.

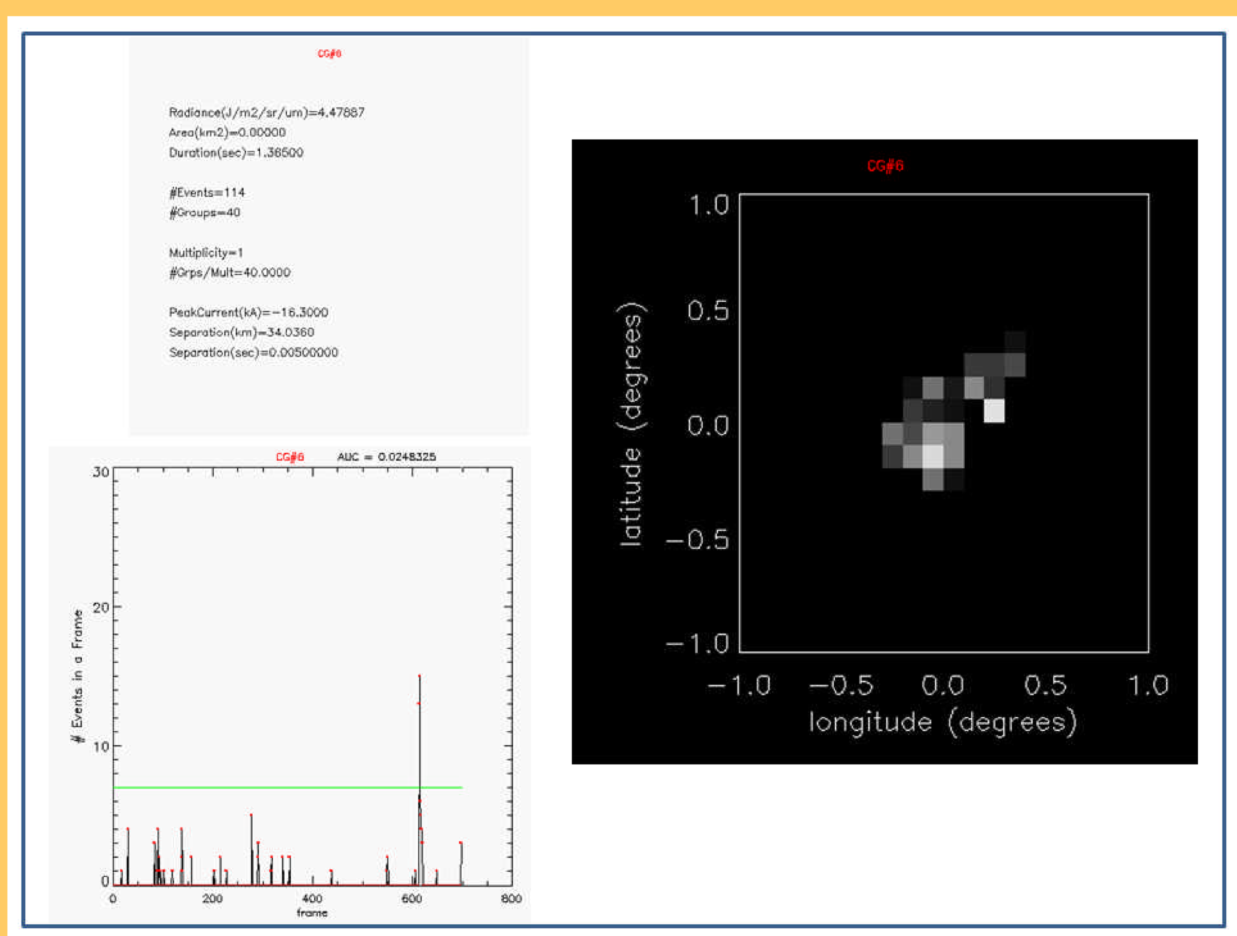


Figure 4. Sample ground flash showing optical events in space and time.

Fig. 4 shows an OTD ground flash. The upper right panel is a plan view of the optical emissions in the flash, and the lower left panel shows the number of optical events within each 2 ms instrument frame. Note that the ground flashes often have ≥ 1 frame with ≥ 7 events whereas cloud flashes do not.

3. THEORY FOR RETRIEVING GROUND FLASH FRACTION (a very brief discussion)

Consider a set of $k = 1, \ldots, n$ characteristics given by $(x_{i1}, x_{i2}, \ldots, x_{in})$ for the i^{th} observed flash from space; such a characteristic could for example be flash area, or flash radiance, or MNEG. The average of the k^{th} characteristic for N flashes in a latitude/longitude bin is

$$\bar{x}_k = \frac{1}{N}\sum_{i=1}^{N} x_{ik} = \frac{1}{N}\left[\sum_{j=1}^{N_g} x_{gjk} + \sum_{l=1}^{N_c} x_{clk}\right] = \frac{1}{N}\left[N_g \bar{x}_{gk} + N_c \bar{x}_{ck}\right], \quad (1)$$

$$\bar{x}_k = \left[\alpha \bar{x}_{gk} + (1-\alpha)\bar{x}_{ck}\right], \quad (2)$$

where,

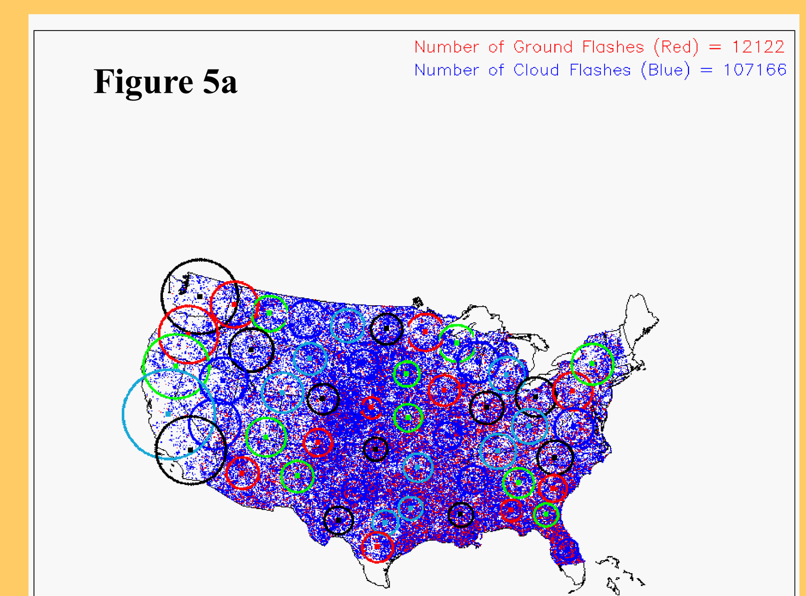
$$\alpha \equiv \frac{N_g}{N}. \quad (3)$$

We don't know N_g (the # of ground flashes in the bin), but one can obtain solutions in terms of the means (which are estimated using the population mean estimates μ, obtained from distributions like those in figures 2 & 3; i.e., we invoke the Central Limit Theorem of statistics):

$$\alpha = \frac{\sum_{k=1}^{n}(\bar{x}_{gk}-\bar{x}_{ck})(\bar{x}_k-\bar{x}_{ck})}{\sum_{k=1}^{n}(\bar{x}_{gk}-\bar{x}_{ck})^2} \cong \frac{\sum_{k=1}^{n}(\mu_{gk}-\mu_{ck})(\bar{x}_k-\mu_{ck})}{\sum_{k=1}^{n}(\mu_{gk}-\mu_{ck})^2} \quad (for\ \ n>1), \qquad \alpha = \frac{(\bar{x}_k-\bar{x}_{ck})}{(\bar{x}_{gk}-\bar{x}_{ck})} \cong \frac{(\bar{x}_k-\mu_{ck})}{(\mu_{gk}-\mu_{ck})} \quad (for\ \ n=1). \quad (4)$$

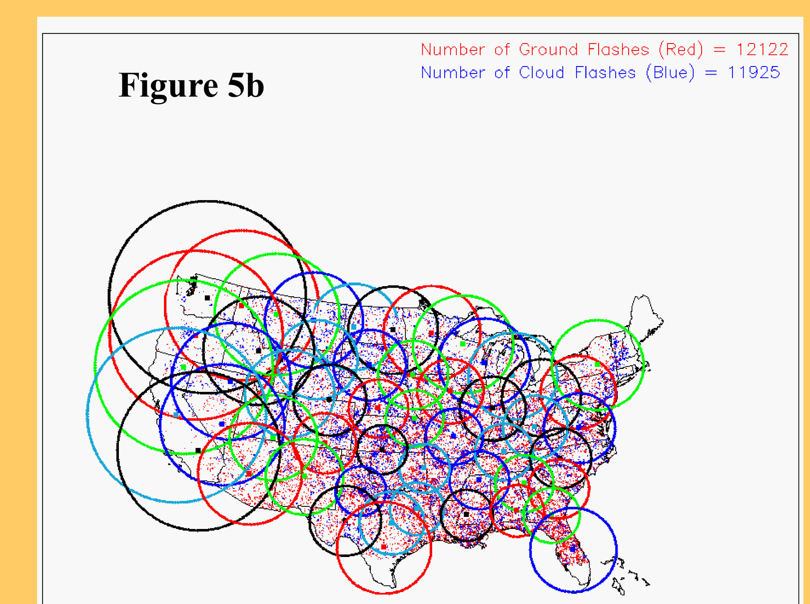
4. APPLICATION, RESULTS, & SUMMARY

We used National Lightning Detection Network (NLDN) data to partition 5 years of CONUS-only OTD flashes into ground and cloud flashes. We then picked 52 locations across CONUS. At each location we picked the radius of a circle that enclosed 1000 OTD flashes (see **Fig. 5**). The circles are colored only to help distinguish the circles for plot clarity. We then applied the retrieval equations in (4). For n>1 we obtained good results (i.e., small retrieval errors in α) when characteristics like flash duration and flash # groups were *not* included. Overall, our best results were obtained when we used the simple retrieval equation (n = 1) with the MNEG characteristic. The rms retrieval error, R, in α over the 52 regions averaged 0.086, or just 8.6% of the full range 0-1 of α (see **Fig. 5** for specific values of R). Note in figure 5 that the value of $\bar{\alpha}$ shown is the true mean value across the 52 regions; this mean value increases from left (figure 5a) to right (figure 5c) since the number of cloud flashes is intentionally depleted from left to right. *In summary, the results shown here clearly indicate that reasonable retrievals of ground flash fraction can be obtained over CONUS when the population mean estimate of MNEG (the maximum # of optical events in an optical group) is used. Since MNEG is a "peak return stroke detector" parameter that does not vary significantly over CONUS, then it might not vary significantly over the globe, in which case this retrieval process would also work globally.*



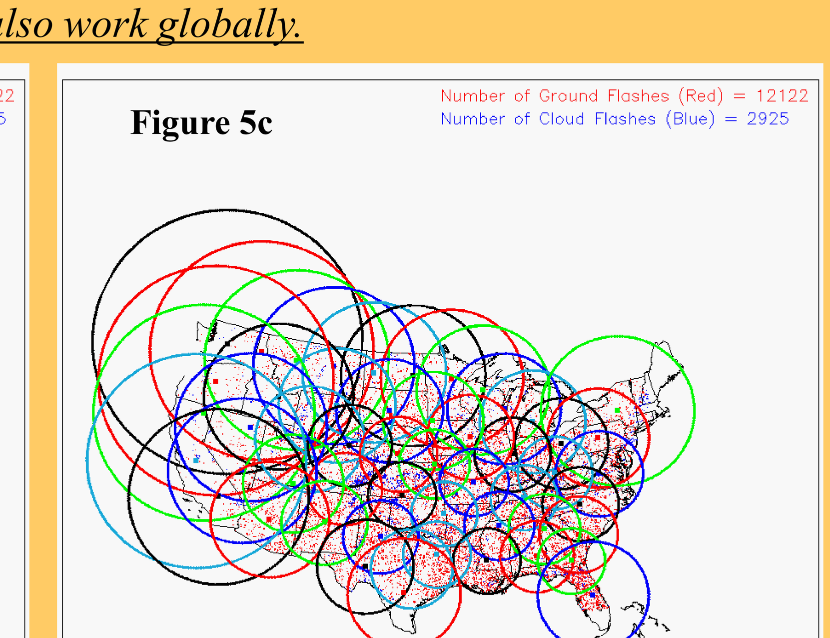
R = 0.061

$(\bar{\alpha} \pm \sigma = 0.101 \pm 0.045)$



R = 0.085

$(\bar{\alpha} \pm \sigma = 0.506 \pm 0.124)$



R = 0.111

$(\bar{\alpha} \pm \sigma = 0.810 \pm 0.088)$

5. REFERENCES

Bey, I., D. J. Jacob, R. M. Yantosca, J. A. Logan, B. D. Field, A. M. Fiore, Q. Li, H. Y. Liu, L. J. Mickley, M. G. Schultz, Global modeling of tropospheric chemistry with assimilated meteorology: Model description and evaluation, *J. Gephys. Res.*, **106**, 23073-23096, 2001.

Huntrieser, H., H. Schlager, C. Feigl, and H. Holler, Transport and production of NO_x in electrified thunderstorms: Survey of previous studies and new observations at midlatitudes, *J. Geophys. Res.*, **103**, 28247-28264, 1998.

Koshak, W. J., M. N. Khan, A. P. Biazar, M. Newchurch, R. T. McNider, A NASA model for improving the lightning NOx emission inventory for CMAQ, Joint Session: 4th Conference on the Meteorological Applications of Lightning Data and and the 11th Conference on Atmospheric Chemistry; *89th Annual AMS Conference*, Phoenix, AZ, January 11-15, 2009.

Koshak, W. J., OTD observations of continental US ground and cloud flashes, *13th International Conference on Atmospheric Electricity*, Beijing China, August 13-17, 2007.

Lee, D. S., I. Kohler, E. Grobler, F. Rohrer, R. Sausen, L. Gallardo-Klenner, J. G. J. Olivier, F. J. Dentener, and A. F. Bouwman, Estimations of global NO_x emissions and their uncertainties, *Atmos. Environ.*, **31**, 1735-1749, 1997.

Martin, R. V., Sauvage, B., Folkins, I., Sioris, C. E., Boone, C., Bernath, P., and Ziemke, J.: Space-based constrains on the production of nitric oxide by lightning, *J. Geophys. Res.*, **112**, D09309, doi:10.1029/2006JD007831, 2007.

Schmidt, G.A., R. Ruedy, J.E. Hansen, I. Aleinov, N. Bell, M. Bauer, S. Bauer, B. Cairns, V. Canuto, Y. Cheng, A.Del Genio, G. Faluvegi, A.D. Friend, T.M. Hall, Y. Hu, M. Kelley, N.Y. Kiang, D. Koch, A.A. Lacis, J. Lerner,K.K. Lo, R.L. Miller, L. Nazarenko, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, G.L. Russell, Mki. Sato, D.T. Shindell, P.H. Stone, S. Sun, N. Tausnev, D. Thresher, and M.-S. Yao, Present day atmospheric simulations using GISS ModelE: Comparison to in-situ, satellite and reanalysis data. *J. Climate*, **19**, 153-192, doi:10.1175/JCLI3612.1, 2006.